MANGALORE UNIVERSITY

A FINAL SYNOPSIS
OF THE PH.D. THESIS TO BE SUBMITTED TO MANGALORE UNIVERSITY
FOR AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN
GEO-INFORMATICS

ON

COASTAL MULTI-HAZARD VULNERABILITY AND RISK ASSESSMENT ALONG THE ANDHRA PRADESH COAST USING GEOSPATIAL TECHNIQUES

BY
R. S. MAHENDRA
SCIENTIST-E
INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES,
HYDERABAD

UNDER SUPERVISION OF
DR. P. A. FRANCIS.
SCIENTIST-F
INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES,
HYDERABAD

February 2023

Abstract

The impacts of climate change are experienced worldwide, however, its effects are changing locally, and accordingly, adaptive capacities, sensitivities, and plans need to be worked out. The areas with dense populations and bio-diversity are most vulnerable. Climate change has enhanced the sea-level rise and exacerbated the incident coastal hazards that made coasts more vulnerable. The coastal vulnerability assessment due to oceanic multi-hazards is a component of this study focused on estimating the coastal zones along Andhra Pradesh exposed to different oceanogenic hazards. The main sub-components of the coastal exposure to multi-hazard assessment are (i) the spatial extent of inundation during the extreme events along coastal zones due to high waves of cyclones & Tsunamis, (ii) shoreline change, (iii) sea-level change and (iv) high-resolution coastal elevation. In this regard, a projected coastal vulnerability that could impact up to the village level for a 100-year return period was estimated by a holistic method with the aid of geospatial tools. This study brought out the risks of coastal 706 numbers of villages, and eight cities were exposed to Coastal Multi-hazard zones (CMZ). The results of the study revealed a total of 10180 km^2 of coastal zones were exposed to inundation along the Andhra Pradesh coast. Of these, 70% of the total CMZ are recorded only under Krishna, Godavari, Guntur, and Prakasam districts, suggesting these coasts were more vulnerable. These coasts comprise large low-lying coastal areas highly exposed to ocean hazards. It was demonstrated that the CMZ records a negative correlation (-0.65) with elevation and a positive correlation (0.34) with exposure index, this revel that the elevation data is very critical in assessing CMZ areas. The shoreline change study suggests that 7% of coastal zones were at high risk due to erosion mainly observed along the headlands of the Krishna-Godavari delta as per the shoreline change rate of 1972-2019.

The socio-economic vulnerability assessment is another component of this study considered to address the impacts. This was conducted at the village level along the Andhra Pradesh coast and building level at the selected location. This assessment intended to capture the geospatial extent and distribution of the elements exposed to coastal multi-hazards and their degree of vulnerability to facilitate improved mitigation and necessary resilience strategies. Hence, The Exposure Index (EI) was calculated based on the oceanogenic Multi-Hazard Zones (MHZ) mentioned above and is

categorized into different exposure indexes based on the coastal elevation. This exposure is integrated with geospatial socio-economic data to assess the sensitivity and adaptive capacity of the villages exposed to CMZ. The socio-economic vulnerability assessment used 16 socio-economic risk indicators derived from census 2001 data and ten indicators surveyed at the building level. Further, the Sensitivity Index (SI), Adaptive Capacity Index (ACI), Socio-Economic Vulnerability Index (SEVI) and Cumulative Coastal Vulnerability Index (CCVI) were calculated at the village and building levels. The CCVI was estimated using the EI, SI, and ACI. At the same time, SEVI was calculated using ACI and SI. The current study suggests 23 villages comprise 6000 households associated with 0.022 million people under the very high SEVI category. A total of four villages, including 1000 households containing 3000 people, were in the very high cumulative Vulnerability Index category. The 1985 buildings in the selected parts of the study area were under very high SEVI. The entire 145 buildings in the village chosen were under very high SEVI. The decision matrix generated at the village and building levels will help decision-makers identify contributing risk indicators at each village/building. The government can implement suitable policy interventions for risk reduction and resilience based on the contributing ACI and SI parameters. The results of this study also provide critical inputs for disaster management and adaptations in order to enhance the resilience of the coastal communities.

Table of Contents

Abstract 2

Chapter 1 1

1. Introduction 1

1.1. Coastal Zones 1

1.2. Need and Justification 2

1.3. Study area 2

1.4. Objectives and outline of Study 4

Chapter 2 6

2. Data and Methods 6

2.1. Data Used 6

2.2. Methods 7

2.2.1. Multi-hazard Vulnerability Mapping 8

2.2.2. Socio-economic Vulnerability mapping 9

2.2.3. Village Level Socio-economic Vulnerability Assessment 10

2.2.4. Building Level Socio-economic Vulnerability Assessment 13

3. Multi-hazard Vulnerability Assessment 15

4. Socio-economic Vulnerability Assessment 18

Chapter 5 23

5. Summary and Conclusions 23

References 25

List of Figures

Figure 1. Map depicting the study site, area of building level assessment and locations of the tide gauge stations. 3
Figure 2. Proposed methodology for assessment of multi-hazard vulnerability 9
Figure 3. The methodology adopted for the assessment of CCVI and SEVI 10
Figure 4. Estimated shoreline change rates along the Andhra Pradesh coast. 16
Figure 5. The cumulative Vulnerability index was estimated using the Sensitivity Index, Adaptive Capacity Index and Exposure Index 18
Figure 6. The decision matrix is drawn against SI and ACI shows the vulnerable villages (b) and the size of the dot represents the population in the building, and color represents the SEVI. The contributing factors (a) of the representative village. 19
Figure 7. Sensitivity Index, Adaptive Capacity Index, Cumulative Coastal Vulnerability Index and Socio-Economic Vulnerability Index of the Individual buildings 20
Figure 8. The decision matrix highlights vulnerable buildings of the Gilakaladindi village (b). The dot's size is the building's population, and the color indicates SEVI. The contributing factors of the representative building (a) and the location of the building is marked in a circle in the 3D map (c). 21

List of Tables

Table 1. Data used for the current study 6
Table 2 List of primary and secondary data used in the current study 7
Table 3. Details of exposure and socioeconomic indicators of coastal villages exposed to CMZ in the current framework 11
Table 4. List of socio-economic indicators of buildings used to estimate the CCVI and SEVI and assigned data ranking 14

Chapter 1

1. Introduction

Climate change is a highly challenging environmental phenomenon globally due to its complex nature (Ojwang et al., 2010). Though climate change is a global phenomenon, its impacts vary locally, and accordingly, exposure, adaptive capacities, sensitivities, and strategies need to be worked out (Piya et al., 2012). Tropical ecosystems associated with dense populations and biodiversity are the most vulnerable (Velepucha et al., 2016). The effects are noticeable in the low-lying areas of the tropics and sub-tropics inhabited by lower-income people (McCarthy et al., 2001). The livelihoods and economies of the coastal populations are dominated by agriculture, aquaculture, forest products, and marine resources that are highly sensitive to climate variations. That can impact the production of these systems affecting income, production cost, supplies, commodities, food storage, livestock and economic reserves (Leary et al., 2008). Implications of climate change and enhanced sea-level rise have worsened the situation in southern and southeastern Asia (Wong et al. 2014). Besides, colossal pressure builds up in these areas due to high population growth and developmental activities.

1.1. Coastal Zones

Coastal zones of India are one the climate-sensitive regions among the four considered by INCCA (2010). Hence it is imperative to conduct a systematic assessment of the coastal vulnerability for better preparedness. Several vulnerability studies were carried out on the Indian coast (Mani Murali et al., 2013; Chandrasekar et al., 2013; Kumar et al., 2010; Hegde and Reju, 2007; INCOIS, 2012; Dwarakish et al., 2009; Rao et al., 2009) based on the geospatial approach (Rani et al. 2015). Most of these studies understated the importance of social and economic parameters in highlighting the physical vulnerability or improving the adaptive capacity to climate change, except very few studies (Krishnan et al., 2019; Umamaheswari et al., 2021 and Maiti et al., 2015).

1.2. Need and Justification

Coastal zones of low elevation worldwide are exposed to oceanic hazards, and the population and infrastructure in these zones are vulnerable. Hence, climate change has a substantial effect on the life and livelihood of the communities along the coast, and hence the imperative of vulnerability assessment worldwide is on high priority (Dolan and Walker, 2004). Scientific evaluation of vulnerability helps the government authority to identify, analyze, and plan to address the underlying causes of disasters. Well-organized efforts to reduce exposure and vulnerability of lives will improve their preparedness and resilience to cope with hazards besides wiser land and environment management (Saxena et al., 2013). Therefore, assessing coastal vulnerability and its extent is necessary to build resilient communities to reduce the risk and enhance preparedness and management.

In this regard, geospatial tools also provide a vital opportunity to consume large primary/secondary geospatial data collected from various sources. Coastal multi-hazard vulnerability assessment demarcated coastal multi-hazard zones (CMZs) representing exposure of the coastal zones to oceanic hazards. Further, socio-economic vulnerability assessments falling under CMZs (exposed) were conducted to understand the adaptive capacity and sensitivity of the coastal communities. Based on these parameters, the cumulative coastal vulnerability and socio-economic vulnerability at the village and building levels were assessed. These assessments help coastal policymakers to make appropriate decisions at the village and individual building levels to prepare intervention measures. Further, the results of the current study are contributing toward national initiatives such as the National coastal Mission (NCM), an initiative component under the National Action Plan to Climate Change (NAPCC), ICZMP and the prime minister's ten-point agenda on disaster risk reduction.

1.3. Study area

The current study site comprises coastal zones of Andhra Pradesh Indian mainland East Coast (Figure 1) along the western boundary of the Bay of Bengal. Andhra Pradesh coast is located between 12º 14' and 19º 54' N latitudes and 76º 46' and 84º 50' E longitudes. The state of Andhra Pradesh is the 7th largest state with a geographic

area of 1,60,205 km^2 with two major geopolitical divisions: Rayalaseema and Coastal Andhra. It is a maritime state sharing 912 km of coast with the Bay of Bengal in the eastern parts of Andhra Pradesh's coastal zones extending from pullicat lake in the south to Ichapuram in the north (CCZMCSB, 2021). The study area is the Andhra Pradesh coastal zones encompasses the nine districts: Nellore; Prakasam; Guntur; Krishna; East Godavari; West Godavari; Visakhapatnam; Srikakulam and Vizianagaram.

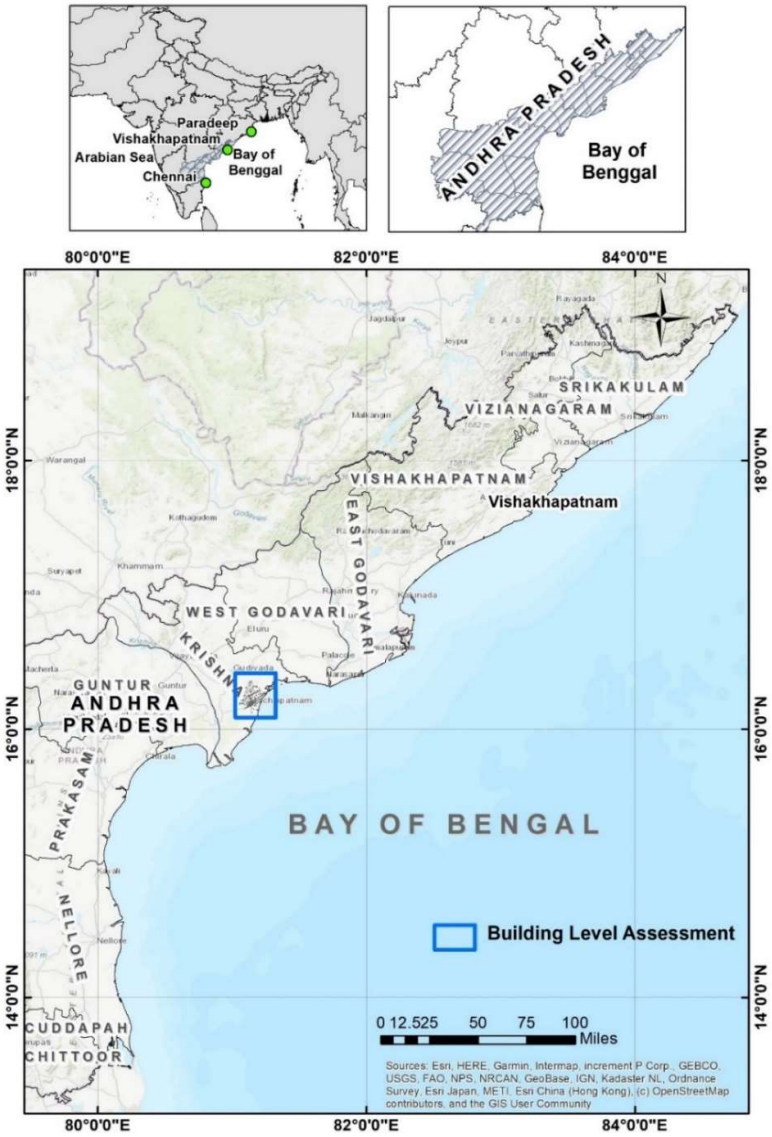

Figure 1. Map depicting the study site, area of building level assessment and locations of the tide gauge stations.

Andhra Pradesh State comprises a population of 49.67 million with an average density of 304.5 people/km^2 (as per the 2011 Indian Census). These coastal zones are densely populated are under huge pressure. These coastal zones account 1/3rd of the total land area comprising 2/5th of the population covering 2482 villages (Somayajulu 2005). Total of 500 villages are situated in the vicinity of 5km from the coast and 257 villages are just located within one kilometer from the coast, a total of 220 villages share a boundary with the coastline (Mahendra et al., 2021). The total geographic area of 92,906 km^2 consists of a population of 34,193,868 that constituting a density of 368 people/km^2 only from the coastal districts (Mahendra et al. 2021).

The coastlines of Andhra Pradesh are associated with large low-lying areas between East Godavari to Nellore districts that are exposed to oceanic hazards. These areas are experiencing inundation due to cyclones, floods, tsunamis, and continuously rising sea levels. It was evident that the recent Hudhud cyclone that hit the Andhra Pradesh coast in 2014 resulted in the huge loss of 90 thousand crores (about US$20000 Million) worth of properties (Business Today 2019). Besides, the coasts of Andhra Pradesh are experiencing coastal erosion and are expected to lose the coastal land of 48 km^2 during 1990-2008 (DNA India 2019). It was reported that the Krishna-Godavari deltaic regions of the Guntur, Krishna, East and West Godavari districts are highly vulnerable to storm surge flooding up to a large extent of 60 km due to large low-lying coastal rivers (Rao et al. 2020). The extensive inundations in these areas are attributed to the cumulative impact of river floods, cyclone-induced rains, and storm tides (Chen et al. 2012). The districts in the Godavari delta are most affected as more than 50% of inundations are due to changing climatic scenarios (Rao et al. 2020).

1.4. Objectives and outline of Study

- Assessment of shoreline dynamics and estimation of trend
- Assessment of change in the long-term sea level and their trends
- Estimation of extreme water levels and their return periods
- Assessment of multi-hazards zones along the coastal areas

- Assessment of the risk associated with hazards
- Building level risk assessment
- Calculation of the Sensitivity and Adaptive Capacity of exposed villages and buildings based on the social and economic risk indicators
- Development of Socio-economic Vulnerability Index (SEVI) and Cumulative Coastal Vulnerability Index (CCVI) framework for the vulnerability estimations at village level and building level
- Framework for the decision matrix for the policy interventions at the village and building level

Chapter 2

2. Data and Methods

2.1. Data Used

A list of data used for the multi-hazard vulnerability assessment is provided in Table 1. The Landsat data from the sensors MSS, TM, ETM, ETM+ and OLI were used for the calculation of the shoreline change rate. The ALTM and cartosat-1 DEM were used as sources of the topographic data. The sea-level change rate was calculated using the PSMSL data downloaded from the GLOSS website. Whereas, the hourly tide gauge data obtained from SOI were used for the calculation of the extreme water levels. The published data on extreme events such as storm surges, tsunamis and other coastal events were collected as additional data.

Table 1. Data used for the current study

Parameter	Data used	Spatial Resolution (m)	Period
Coastal Topography	ALTM	5	2004-09
	Carto-DEM	10	2005-08
Shoreline change rate	LANDSAT MSS	57	1972
	LANDSAT-TM & LANDSAT-ETM	30	1989-2000
	LANDSAT-ETM+	30	2010
	LANDSAT-OLI	30	2019
Extreme Water Level	Hourly Tide Data from SOI	--	1879-2007
	Published Literature*		
Sea-level change rate	Monthly sea level data from GLOSS	---	1900-2013

-- Not Applicable
* events extracted from published literature.

The socio-economic vulnerability of the exposed villages was carried out using the data provided in Table 2. The census data of 2001 (Meiyappan et al. 2018) was openly

available from the Columbia University website pertaining to the Andhra Prades coast and was used as a source of the socio-economic data at the village level. Further, The annual rainfall climatology generated based on the 1991-2020 observed rainfall data openly available on the "Climate Change Knowledge Portal" of the World Bank Group was downloaded (URL: https://climateknowledgeportal.worldbank.org/). Buildings were extracted from the UAV data and building-level socio-economic data was collected from the door-to-door survey.

Table 2 List of primary and secondary data used in the current study

Parameters	Data Source	Spatial Resolution (m)	Period
Building Bases	UAV Data	0.12	2016
Building level socio-economic data	Field survey	--	2016
Village Level Socioeconomic data	Census of India 2001	--	2001
Rainfall	Annual Rainfall Climatology	50000	1991-2000

-- Not Applicable

2.2. Methods

The current study comprises two significant aspects (i) multi-hazard vulnerability assessment and (ii) socio-economic vulnerability assessment. The first one is focused on estimating the coastal multi-hazard zones (CMZs) that represent coastal exposure to oceanogenic hazards based on the holistic approach. This represents the physical vulnerability of the coast, which is probably getting inundated due to oceanic hazards such as sea level rise, erosion, storm surge, tsunami and coastal floods due to oceanic hazards. The second is focused on assessing the sensitivity and adaptive capacity of the coastal villages and buildings exposed to oceanogenic hazards considered in (i). This analysis further led to calculating the socio-economic vulnerability index (SEVI) of villages and buildings. SEVI assessment yields information on the vulnerability level of the villages and buildings and helps to draw the village/building specific

intervention measures to make village/building resilient against hazards. The methodology adopted for achieving these two aspects is briefed below.

2.3. Multi-hazard Vulnerability Mapping

The schematic assessment of coastal vulnerability to multiple oceanogenic hazards utilized the parameters of sea-level trend, extreme water level & their return periods, shoreline-change rate and coastal elevation contours (Figure 2). The multi-hazard vulnerability is a more robust holistic technique that gives the detailed spatial extent of the vulnerability by coastal inundation from oceanogenic disasters. This method is the same as Mahendra et al. (2010, 2011). Still, it uses the long-term hourly sea level data from tide gauges and other extreme events reported in the published sources to estimate the more accurate extreme water level instead of only surge height (Mahendra et al., 2021). Coastal Multi-hazard Zones (CMZs) were derived using parameters: shoreline change rate, sea-level trend, recurrence of extreme water levels, and detailed coastal elevation. Besides, future shoreline position and sea level expected in 100 years were calculated based on the estimated trends. Using ArcMap software, the study area's elevation contours were prepared using a merged elevation dataset generated using the very detailed topography mentioned in Table 1. Inundation levels for each station were the sum of the expected extreme water level and sea level in 100 years. Then the corresponding inundation level contour was selected as the composite multi-hazard line. The multi-hazard zone is between the coast and the composite hazard line. This was based on the assumption that the surge of a water level of 5 m will impact up to 5 m land contour, and 10 m will impact up to 10 m land contour (Dube et al. 2009). The return period of the extreme water levels for the next 100 years was calculated from the hourly tide gauge data and other published data. The union of the future shoreline and extreme water levels and sea level in 100-year will be the coastal multi-hazard zone. This information was overlaid in the GIS environment and analyzed.

The assessment of CMZs involves utilizing the host of remotely sensed data collected from different satellites and observations. The versatile geospatial technology and tide data processing techniques were used to synthesize the primary data used in the study. The maritime district's coastal exposure index (CEI) is a function length of the district's coastline to the total geographic area. In addition, the villages pertaining to

these CMZs were listed with their percentage of the area falling under the CMZ. This CMZ was validated with the ground truth information pertaining to the Hudhud cyclone and the results suggest good agreement with the MHVM maps.

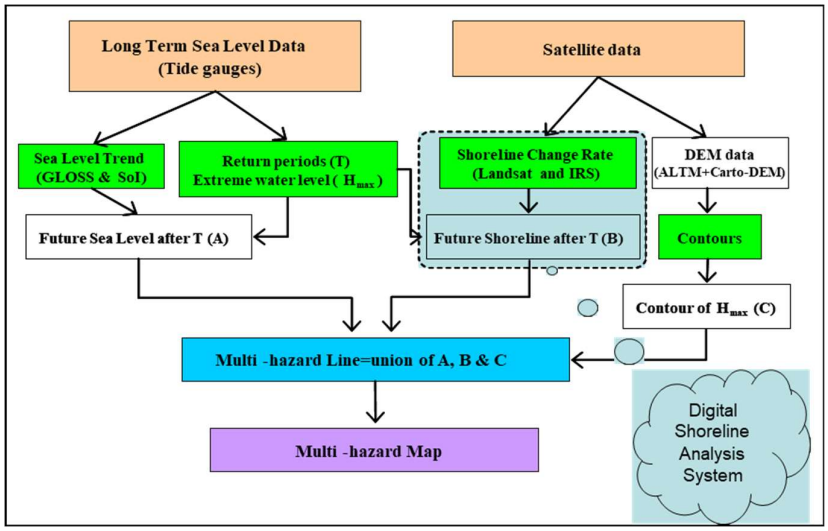
Long Term Sea Level Data (Tide gauges)
Satellite data
Sea Level Trend (GLOSS & SoI)
Return periods (T) Extreme water level (H_{max})
Shoreline Change Rate (Landsat and IRS)
DEM data (ALTM+Carto-DEM)
Future Sea Level after T (A)
Future Shoreline after T (B)
Contours
Contour of H_{max} (C)
Multi -hazard Line=union of A, B & C
Digital Shoreline Analysis System
Multi -hazard Map

Figure 2. Proposed methodology for assessment of multi-hazard vulnerability

2.4. Socio-economic Vulnerability mapping

The present study attempts to demonstrate the framework of socio-economic vulnerability developed by Krishnan et al. (2019) in the village level assessment and further down to the individual buildings was attempted in this study. The methodology framework of the current study is provided in Figure 3. The framework's utility in estimating vulnerability and its influencing aspects at the village/building level helps identify the responsible socio-economic indicator for suitable adaptive action at the micro-level. The current study outcomes form a starting point for monitoring and evaluating interventions over a more extended period. The socio-economic vulnerability assessment has progressively presented an idea of contributing data on coastal communities exposed to climate change risks to help officials and planning specialists in micro-level decision-making. Hence, it was attempted here to calculate the socio-economic vulnerability condition of the coastal villages and buildings exposed to the risks of climate change along the coastal zones of Andhra Pradesh.

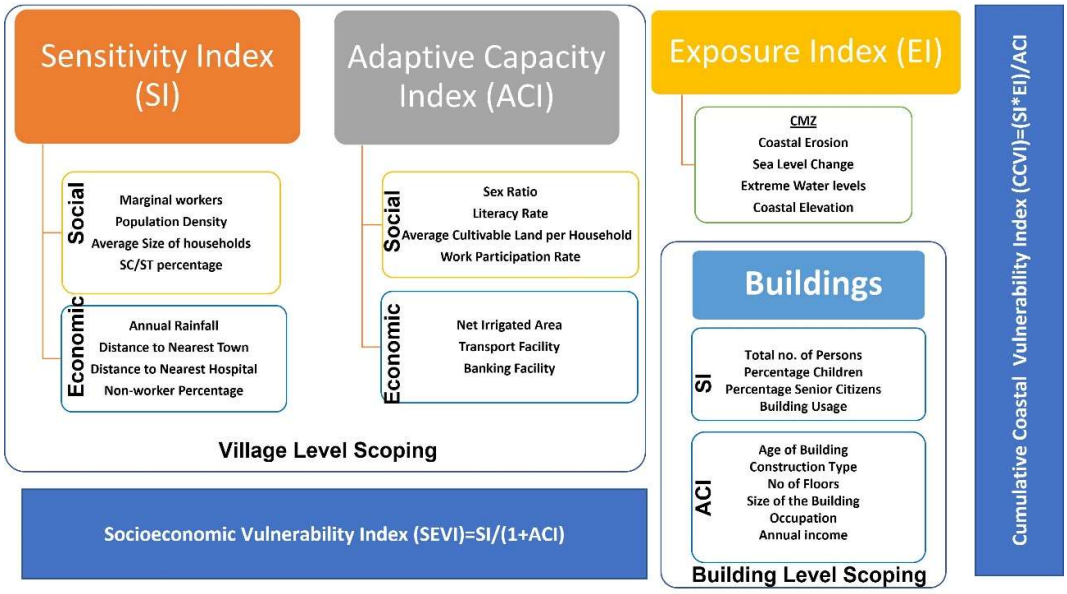

Figure 3. The methodology adopted for the assessment of CCVI and SEVI

The exposure index was calculated using the Coastal Multi-hazard Zones (CMZ) approach similar to the Mahendra et al. 2021 and coastal elevation within the CMZ. The risk classes within CMZ (say CMZ risk (CMZR)) is estimated based on the coastal elevation data. The coastal areas less than 1m, 1-2m, 2-3m and more than 3m were categorized into "Very High", "High", "Moderate" and "Low" exposure categories, respectively. The exposure at the village level was calculated based on the following Equation 4.

$$EI=(4a+3b+2c+d) \qquad ---(4)$$

Where 'a' is the percentage of the village's area recorded under Very high exposure (elevation less than 1m), 'b' is the percentage of the village's area recorded under high exposure (elevation 1-2m), 'c' is the percentage of the village's area recorded under Medium Exposure (elevation 2-3m) and 'd' is the percentage of the village's area recorded under Low Exposure (>3m).

2.4.1. Village Level Socio-economic Vulnerability Assessment

A total of 19 indicator parameters (Table 3) were derived from the census data of 2001 and other sources, as mentioned in the data section.

Table 3. Details of exposure and socioeconomic indicators of coastal villages exposed to CMZ in the current framework

Category	Indicators	Definition/measurement
Exposure-Coastal Multi-hazard zone (CMZ) Risk	Coastal Erosion (CE)	Areas under erosion in 100 years based on the shoreline change rate calculated from satellite data acquired during 2072-2019 (m/y)
	Sea Level Change (SLC)	Sea level trend calculated based on the monthly mean tide data from PSMSL (mm/y)
	Extreme Water levels (EWL)	Extreme water levels and their return periods depicting the inundation level for the next 100 years based on non-astronomical hourly tide data (m)
	Elevation (ELE)	Elevation of the coastal inundation zone from MSL (m)
Sensitivity (Social)	Percentage of Marginal workers (MW)	The ratio of marginal workers to the total population (%)
	Population Density (PD)	Total number of people living in one sq. km
	Average Size of households (ASH)	The ratio of population to number of households in a village
	SC/ST percentage (SCST)	The ratio of SC & ST population to the total population (%)
Sensitivity (Economic)	Annual Rainfall (RF)	Rainfall climatology (mm/y)
	Distance to Nearest Town (DNT)	The distance from the village to the nearest town (km)
	Distance to Nearest Hospital (DNH)	Distance to the nearest hospital (km)
	Non-worker Percentage (NWP)	The ratio of non-workers and the total population (%)
Adaptive Capacity (Social)	Sex Ratio (SR)	The ratio of females to 1000 males
	Literacy Rate (LR)	The ratio of literates to total population above six years of age (%)
	Average Cultivable Land per Household (ACLH)	The ratio of cultivable land to the number of households (ha)
	Work Participation Rate (WPR)	The ratio of workers to the total population (%)
Adaptive Capacity (Economic)	Net Irrigated Area (NIA)	The ratio of irrigated land to cultivable land (%)
	Transport Facility (TF)	Distance to transport facility (km)
	Banking Facility (BF)	Distance to banking facility (km)

This framework is adopted based on the available indicator parameters similar to Krishnan et al. (2019), except for the improved coastal exposure. Besides, the building level socioeconomic vulnerability index (SEVI) and Cumulative Coastal Vulnerability Index (CCVI) were carried out using 11 indicators (Table 4) pertaining to Exposure (E), Sensitivity(S) and Adaptive Capacity (AC). All the indicators selected in the study were given weightage similar to the study carried out by Krishnan et al., 2019. The internal consistency between the variables of the village-level socioeconomic indicators was calculated using Cronbach's reliability coefficient (Cronbach 1951). The estimated Cronbach's reliability value for the indicators used was 0.59 (very close to the acceptable limit of >0.60, Tseng et al., 2006) suggesting the fairly good reliability of the indicators.

Village level data downloaded from the source associated with socio-economic data were used to calculate the indicators in Table 3. These indicators pertain to sensitivity, and this study normalized adaptive capacity (0-100) to a scale to compare and perform arithmetical operations (Gomez Limon and Sanchez-Fernandez 2010). This normalization was carried out based on the dynamic range of values in each indicator. The Social Sensitivity Index (SI_{social}), Economic Sensitivity index ($SI_{economic}$), Social Adaptive Capacity Index (ACI_{social}) and Economic Adaptive Capacity Index ($ACI_{economic}$) were calculated by averaging the indicators pertaining to respective categories. The Sensitivity Index (SI) was calculated based on the social and economic indicators of sensitivity categories mentioned in Table 3 using equation 5.

$$\textbf{Sensitivity Index (SI)}=(SI_{social}+SI_{economic})/2 \text{ ------(5)}$$

The Adaptive Capacity Index (ACI) was calculated using the following equation 6

$$\textbf{Adaptive Capacity Index (ACI)} =(ACI_{social}+ACI_{economic})/2 \text{ ----(6)}$$

This study's cumulative Coastal Vulnerability Index (CCVI) is a function of sensitivity, adaptive capacity, and exposure. Whereas sensitivity and exposure are directly proportional, adaptive capacity is indirectly proportional, as per Li et al. (2015). Hence, equation 7 was used to estimate the CCVI.

$$\textbf{Cumulative Coastal Vulnerability Index (CCVI)= (EI*SI/ACI) -----(7)}$$

Further, these SI, ACI, and CCVI were rescaled (0-1) based on each index's dynamic range of values. The Socio-Economic Vulnerability Index (SEVI) was calculated to develop a village-level intervention planning framework using equation 8.

Socio-Economic Vulnerability Index (SEVI)=SI/(1+ACI) --------- (8)

The SEVI values obtained for all the villages were rescaled to a 0-1 scale to generate maps and SEVI classes. A total of 4 classes, Very High, High, Medium and Low SEVI classes, were prepared based on the equal interval.

2.4.2. Building Level Socio-economic Vulnerability Assessment

The building bases were digitized using drone-derived images and visual interpretation was employed to extract the building bases. The building height was derived using the Digital Surface Models (DSM) and street-level 360-degree camera survey. The door-to-door survey on the parameters listed in Table 4 was collected and attached to the corresponding building. The spatial data of 54941 buildings were associated with socio-economic data and were used to assess the ACI SI, CCVI and SEVI. The data ranking 1-3 were assigned to individual parameters as mentioned in Table 4. Here the sensitivity and adaptive capacity parameters were only considered based on the data available. The resultant SI and ACI were calculated by the average values of the respective indicators. The CCVI and SEVI were calculated using equations 7 and 8, respectively.

All the index values of SEVI, CCVI, ACI and SI were rescaled to 0-1 scale and generated the corresponding maps representing the different categories “Very high” (0.75-1), “High” (0.5-0.75), “Medium” (0.25-0.5) and “Low” (0-0.25). A decision matrix was prepared by plotting village-level ACI vs. SI of the study area to identify socio-economically vulnerable areas for the appropriate intervention planning. The mid values of ACI and SI were used to make the quadrants. The villages falling under ACI values less than 0.5 and SI values more than 0.5 were considered high socio-economic vulnerable. This decision matrix can analyze the contributing indicators in each village that drive socio-economic vulnerability. The necessary statistical calculations were carried out for understanding the relationship between indicators and the resultant indicators.

Table 4. List of socio-economic indicators of buildings used to estimate the CCVI and SEVI and assigned data ranking

Category	Short Form	Indicator	Data Ranking		
			1	2	3
Exposure	EI	CMZR	1	2	3
Sensitivity	TP	Total Number of Persons	<4	4-10	>10
	PCLD	Percentage Children	<30	30-60	>60
	PSNR	Percentage Senior Citizens	<30	30-60	>60
	BU	Building Usage	Religious and Other	Government, Educational and Commercial	Residential
Adaptive Capacity	AGE	Age of Building (years)	>50	20-50	<20
	CTY	Construction Type	Kutcha and Hut	Moderate and Other	Pukka
	NF	Number of Floors	1	2	>=3
	SB	Size of the Building (m^2)	>100	50-100	<50
	OCC	Occupation	Farming and Other Marginal Job	Other & private job, Educational and Religious	Govt Job and Business
	AI	Annual Income (lakhs)	<1	1-5	>5

Chapter 3

3. Multi-hazard Vulnerability Assessment

The shoreline change assessment was carried out for 48 years, from 1972 to 2019, using Landsat data reveals the large variability in erosion rates and accretion along the coast. The results reveal that a high rate of erosion 66.3 km was recorded along the coasts of West Godavari, East Godavari and Krishna districts (Figure 4a) in the proximity of the Krishna-Godavari (KG) delta. The erosions in these areas were evident due to the dynamic coastal processes by the interplay of the marine-fluvial systems. A moderate erosion rate of 33.9 km was recorded along the small stretches in East Godavari, Krishna, West Godavari and Nellore Districts. At the same time, the low rate of erosion of 180.3 km of coastlines recorded low erosion between Nellore and Vishakhapatnam coasts. The rest of the coastline of 662.9 km was recorded under accretion. The districts Viziayanagaram, Srikakulam and Prakasham were predominantly under accretion. A similar accretion trend was also observed in the earlier study by Sindhu and Rai (2020). However, the 129.8 km of coastlines were under stable conditions and recorded no change.

Coastal Multi-hazard zones (CMZs) estimated by a holistic method recorded the low-lying areas prone to inundation from the disasters that cause coastal inundations (Figure 4b). The potential coastal flooding areas in the 100-year return period were covered under the CMZs. The KG delta's large, low-elevation coastal zones were more exposed and vulnerable than other areas. The coastal areas of East Godavari, Krishna, West Godavari, Guntur, Prakasam and Nellore districts were more vulnerable as CMZ extends up to several kilometers from the coast. Coastal areas of Srikakulam, Vizianagaram and Vishakhapatnam districts were less Vulnerable as they record a comparatively narrow stretch of the CMZ.

There were 1435 villages intersecting with CMZs spread across the coast. The percentage of the CMZ falling under each village was estimated ((Figure 4c). There were 706 villages and eight towns recorded that more than 90% of their geographic area under CMZ were most vulnerable to coastal exposure. The villages and towns from Nellore to East Godavari coastal districts were highly exposed. There were 208 villages recorded with 50-90% of their area in CMZ. The rest of the villages were

recorded as less than 50% of CMZ. Though the percentage of exposure is calculated based on the administrative boundary, the actual location of the habitation needs to be considered for the risk assessment. However, the assets and utilities of the exposed villages are certainly at risk and need attention.

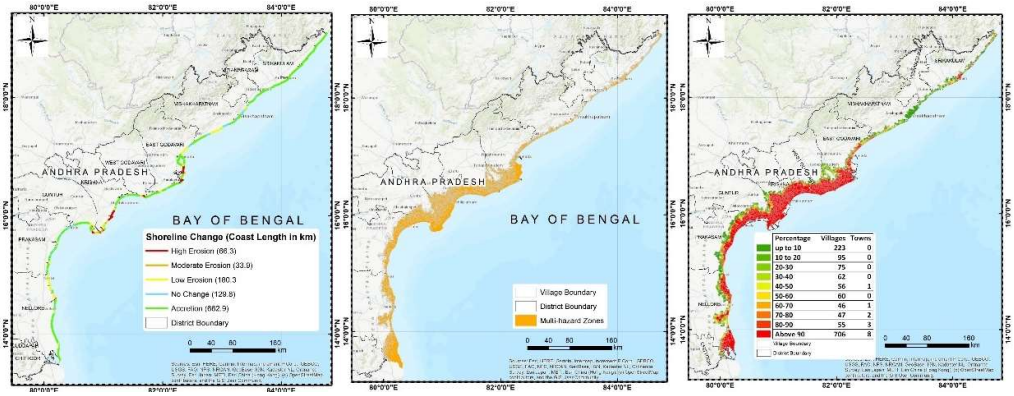

Figure 4. Estimated shoreline change rates along the Andhra Pradesh coast.

The results of a comparison between the total CMZ area with an average elevation within the CMZ area and normalized Coastal Exposure Index (CEI) were conducted. The percentage of CMZ areas recorded highest in Krishna with 30%, followed by East Godavari with 18%, Gunturu with 11% and West Godavari with 10%. These coasts were associated with low-lying areas and higher normalized CEI due to long coastlines, which reveals these districts were more vulnerable and prone to inundations. The relationship between CMZ and coastal elevation was negatively correlated with a correlation coefficient of -0.65. In contrast, the CMZ positively correlates with CEI with a correlation coefficient of 0.34. This analysis suggests a positive correlation of CEI with low elevation areas results in recording the large CMZs along the coastal zones. Hence, it was understood that the elevation data is the primary controlling factor, and the high-resolution DEMs used here enhanced the results.

The high-resolution coastal topography used in the study was enhanced the results by the CMZs representing the coastal exposure (Kulp and Strauss, 2019). In addition, the long-term sea-level data used to estimate the extreme water level and their 100-year return period were very apt in demarcating the inundation level along the coastal zones of the study area (Mahendra et al., 2021). Besides, the multi-temporal Landsat

data of 1973-2019 pertaining to 49 years used for the shoreline change estimation enhanced the accuracy of the shoreline change trend. All the above considerations make this study more accurate in estimating the exposure and physical vulnerability of the coastal zones. Coastal zones along the deltaic regions of the KG delta were highly exposed as the large areas recorded under CMZ. The high exposure was due to the large low-elevation coasts associated with rivers and creeks, allowing inundation into hinterlands (Mahendra et al., 2011). These accurate CMZ maps are appropriate for coastal disaster management and mitigation. Further, the information on the exposure at the village level makes it handy in prioritizing micro-level disaster action plans.

Chapter 4

4. Socio-economic Vulnerability Assessment

Village level Socio-economic Vulnerability: The results of the current study recorded the villages in different ACI, SI, EI, CCVI and SEVI as shown in Figure 5 (a-e). This study recorded 1443 coastal villages exposed to different exposure index categories. The map of the exposure index reveals the coastal villages from East Godavari to Nellore in the south were under very high exposure as these coastal areas were associated with large low-lying areas. The sensitivity of the 18 coastal villages majority in the southern parts of the Nellore district, was very high. The rest of the villages were predominantly medium to high sensitivity. The low sensitivity is limited to only a few villages and towns. In contrast, lower adaptive capacity was observed on either side of Visakhapatnam and few in the southern parts of Nellore. The resultant CCVI map reveals the villages in the parts of the Krishna-Godavari Delta, Guntur, Prakasam and northern parts of Nellore districts were recorded the medium to very high vulnerability.

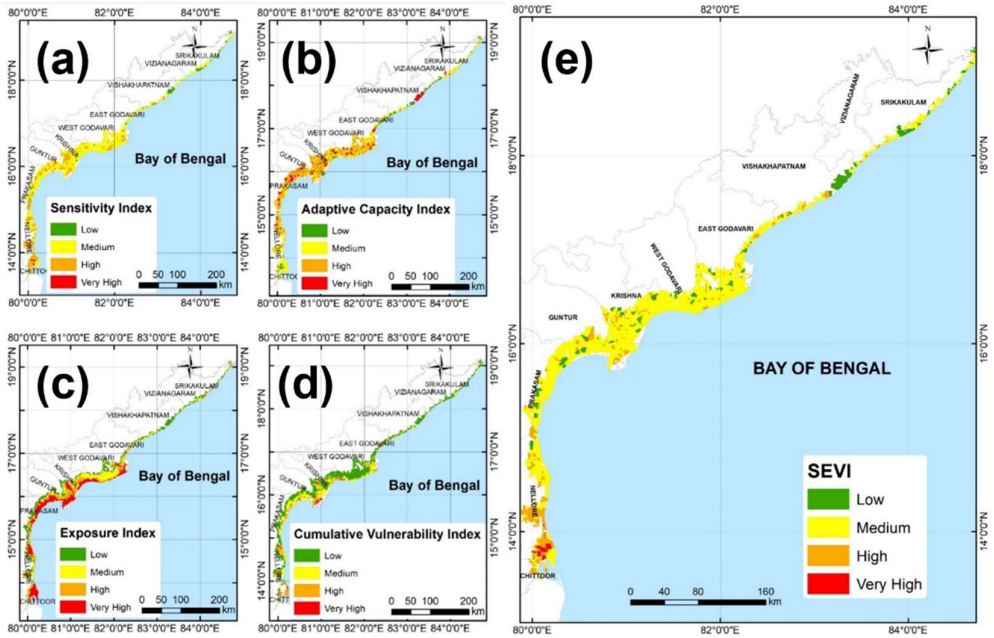

Figure 5. The cumulative Vulnerability index was estimated using the Sensitivity Index, Adaptive Capacity Index and Exposure Index

The SEVI assessment of the current study area reveals southern parts of Nellore district depict very high to medium recording 23 coastal villages in very high SEVI (Figure 5e). The dominant category was medium SEVI spread across the area. The scattered low SEVI villages spread across the study area, and most towns were under the low SEVI category. The correlation coefficients between SEVI and SI suggested a very strong correlation with 0.9 suggesting the coastal communities were more sensitive when compared to the moderate negative correlation coefficient of -0.4 with the adaptive capacity. Among these two social sensitivity and economic adaptive capacities are more contributing to the vulnerability. Whereas, CCVI has very strong correlation coefficient of 0.76 with an exposure index and moderate correlation with sensitivity and adaptive capacity indexes.

Decision matrix for the village level Socio-economic vulnerability: The decision matrix was prepared for the 1443 villages of the current study was plotted, and the matrix can select the individual village to verify the contributing parameters. This tool is handy and allows users to quickly display the vulnerable villages. There were 236 villages recorded in the third quadrant which were highly vulnerable as shown in Figure 6a and the corresponding indicators in Figure 6b. The indicators SCST, DNT from SI and ACLH, NIA and BF from ACI are contributing to the SEVI of the selected village. Similarly, individual villages contributing parameters can be listed to enhance their resilience against oceanogenic hazards. Highlighting contributing indicators is highly useful for coastal planning and policymakers to take suitable intervention strategies to make the vulnerable villages resilient to coastal disasters.

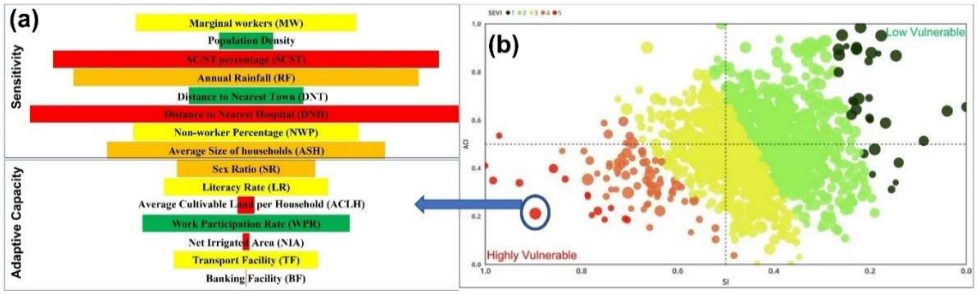

Figure 6. The decision matrix is drawn against SI and ACI shows the vulnerable villages (b) and the size of the dot represents the population in the building, and color represents the SEVI. The contributing factors (a) of the representative village.

Building level Socio-economic Vulnerability: The socio-economic vulnerability of 54941 buildings (Figure 7) was assessed using the sensitivity and adaptive capacity indicators, revealing a predominantly high SEVI category recording 34947 buildings. At the same time, the 1985 buildings were under a very high SEVI category and needed immediate attention and strengthen their resilience. The rest of the buildings were under the medium to low SEVI category. At the same time, the CCVI of the buildings revealed that 48, 182 and 2316 buildings were categorized under very high, high and medium vulnerability, respectively. The rest of the buildings were under the low vulnerability category. The results reveal that the buildings' higher sensitivity (Figure 7a) is more vulnerable based on the considered parameters.

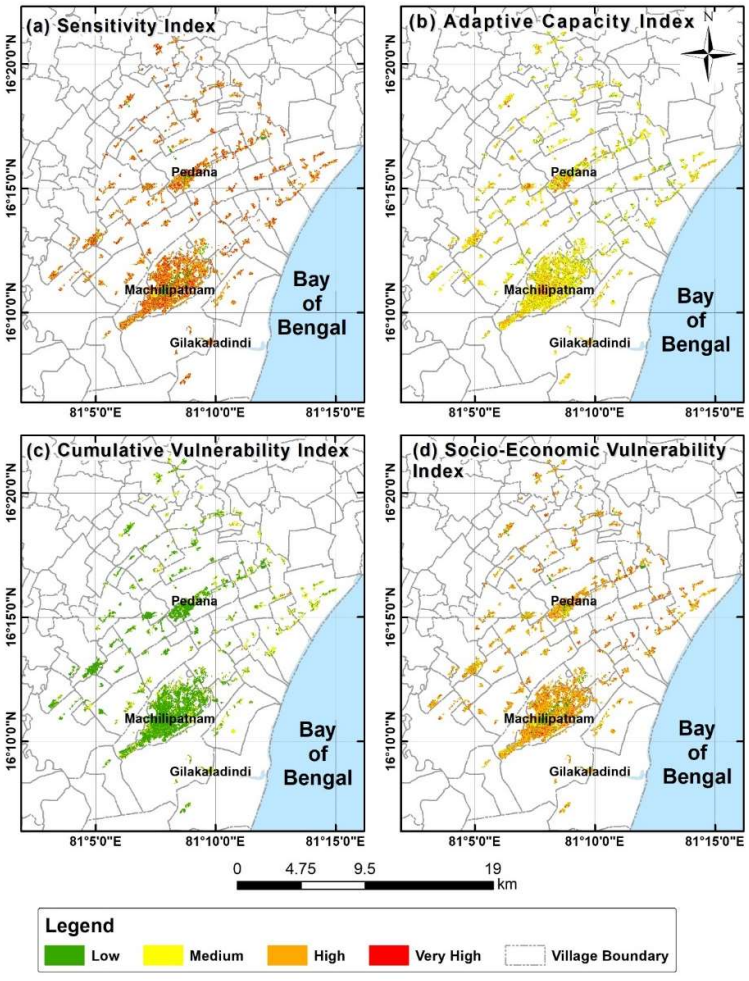

Figure 7. Sensitivity Index, Adaptive Capacity Index, Cumulative Coastal Vulnerability Index and Socio-Economic Vulnerability Index of the Individual buildings

The 3D buildings of the Giddalakandi village (Figure 8c) are colored based on the SEVI to show village level information of buildings with different SEVI calsses.

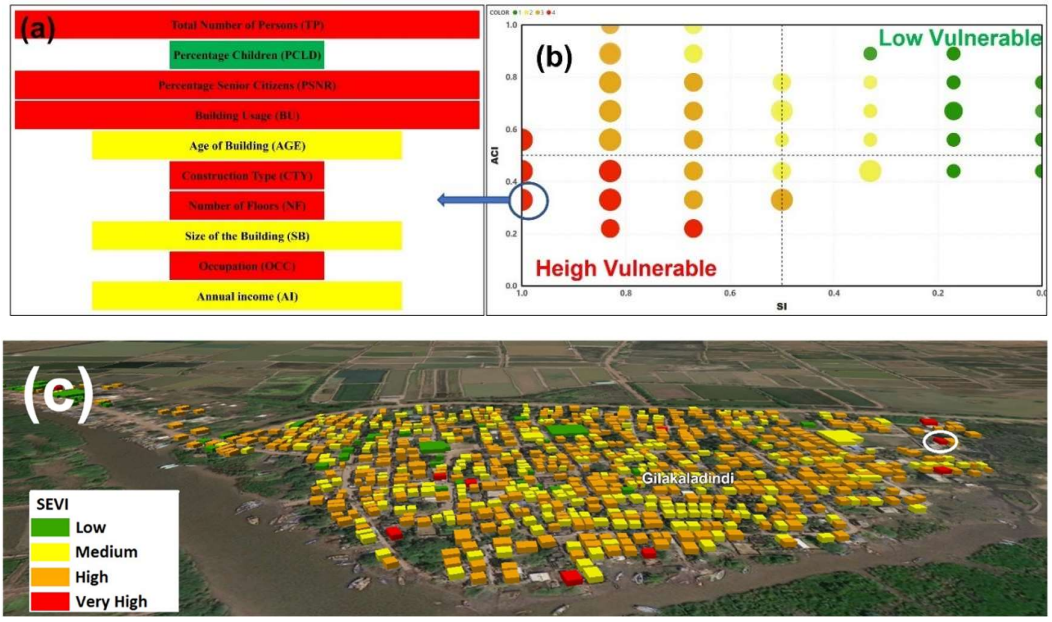

Figure 8. The decision matrix highlights vulnerable buildings of the Gilakaladindi village (b). The dot's size is the building's population, and the color indicates SEVI. The contributing factors of the representative building (a) and the location of the building is marked in a circle in the 3D map (c).

Decision matrix for the building level socio-economic vulnerability: The current framework allows assessing the socio-economic vulnerability at different levels (building, Village, Taluk and District), such as village taluk and district levels. Buildings of Gilakaladindi village were selected as an example, and the SEVI of individual buildings within this village is shown in **Error! Reference source not found.**c. The corresponding decision matrix (Figure 8b) and contributing parameters ((Figure 8a) of the selected vulnerable building is presented in Figure 8. this will help the administrators and policymakers to understand the contributing sensitivity (TP, PSNR and BU) and adaptive capacity (CTY, NF and OCC) indicators that drive the vulnerability. One hundred forty-five buildings were very high; 614 buildings were high SEVI in the selected village. Drivers and buffers of socioeconomic vulnerability of the coastal villages of Andhra Pradesh was discussed and the and proposed interventions was prepared. These are highly useful parameters to understand the grassroot level reasons for the vulnerability conditions of the villages and households.

Further, the specific intervention measeres were also listed to provide inputs for the policy interventions.

The study focused on assessing the SEVI and CCVI and developing a framework based on the ACI, SI and EI. The EI was calculated based on the coastal multi-hazard zone (CMZs) exposed to oceanogenic hazards. Further, the exposure was categorized into different exposure index zones based on the high-resolution elevation DEMs from ALTM and Carto-DEM. These DEMs have enhanced the accuracy of the coastal exposure estimation when compared to the open-source data (Kulp and Strauss, 2019). The social and economic indicators representing the Sensitivity and Adaptive Capacity of coastal villages drawn from Census data of 2001 were used to estimate SI and ACI. The indicators representing village-level social and economic status are yielding in assessing the SEVI. The building level data for the selected area are used based on data available to calculate the vulnerable villages.

Chapter 5

5. Summary and Conclusions

The method used in this study was estimated CMZ that representing the coastal exposure was an appropriate scientific approach. It accurately demarcated the coastal zones exposed to oceanogenic hazards and validated with case studies. The parameters of this study: extreme water levels, shoreline change trends, and sea-level change trends are critical inputs for the assessment of CMZs. The high-resolution coastal elevation data from ALTM and Carto-DEM enhanced the study results in estimating the accurate inundation extent. The long-term satellite data and tide gauge data provided vital scientific input in assessing the shoreline change rate and extreme water level. The geospatial technology used in the current study to prepare the input parameters and synthesize them is versatile and handy. Geographic Information System (GIS) provided a vital opportunity to analyze, derive resultant maps and generate statistics. The results of the CMZ are valuable inputs on the boundary of the coastal zones probable to inundate or be exposed in a 100-year recurrence. Further, assessing the exposed villages to oceanogenic hazards helps in micro-level disaster planning.

The study has confirmed that the coastal areas of the Krishna, East Godavari, West Godavari, Gunturu and Prakasham districts were exposed to oceanogenic hazards due to large low-lying areas. In contrast, the coastal zones of the Srikakulam, Vizianagaram and Vishakhapatnam districts in the northern parts were low vulnerable due to the high coastal zones. Seven hundred six villages and eight towns along the coast are at risk as more than 90% of their areas are recorded under CMZ exposed to coastal inundation. These vulnerable villages and towns need immediate attention and resilient measures to address the adverse impacts. The total area exposed to oceanogenic hazards along the Andhra Pradesh coast is 10180 km^2. The district-level assessments suggested that the Krishna district recorded the highest of 30% of its area under CMZ.

The SEVI and CCVI assessed in the current study highlight the vulnerable villages and buildings exposed to climate-related coastal hazards due to variations in the sensitivity and adaptive capacity. The socio-economic data associated with geospatial

villages and CMZ used in the study are essential parameters to assess the CCVI and SEVI. The geospatial tools used in the current framework are convenient and user-friendly. The decision matrix generated for villages and buildings is robust yet straightforward to quickly identify the vulnerable elements and their governing indicators. All the results generated in the current study are available are the geospatial domain and are compatible with geospatial tools that enable generating vital decisions.

The accurate exposure enhances the accuracy of the results and the CCVI and SEVI. The study highlights the 23 villages in Nellore that recorded high SEVI are under risk. The CCVI reveals that the four villages were very high vulnerable. The social and economic status plays a vital role in the lower adaptive capacity of coastal villages of the study area. The buildings assessed in the present study were primarily low CCVI as adaptive capacity was competitively higher. On the contrary, the higher sensitivity of the buildings was largely under high SEVI.

The results and maps on the CMZ, CCVI and SEVI were generated based on the well-established scientific approach. This CMZ information is beneficial in distinguishing the coastal disaster setback line for the coastal zone management plans. The results of the current SEVI framework are beneficial for the policymakers to take appropriate area-specific intervention measures. Those measures strengthen the adaptive capacity and reduce the sensitivity to bring down vulnerability and develop a resilient coastal community. The outcome information of this study is helpful in the national initiatives for the NCM and ICAMP. This work also contributes to the recent Indian "Prime Minister's Ten Point Agenda on DRR". The detailed information on vulnerability at the village and building levels are vital inputs for micro-level disaster and coastal planning. This framework and results of the current study contribute to the global initiatives such as Sendai Framework's components, Sustainable Development Goals (SDGs) and Millennium Development Goals MDGs.

References

Business Today (2019) Cyclone Fani caused loss of over Rs 9,000 crore in Odisha; 1.6 crore people affected. *Available at:* https://www.businesstoday.in/latest/economy-politics/story/cyclone-fani-news-odisha-fani-cyclone-disaster-total-loss-due-to-cyclone-fani-203012-2019-06-07. Accessed 06 December 2021

CCZMCSB, 202. Andhra Pradesh Information. Available at: http://iomenvis.nic.in/index3.aspx?sslid=878&subsublinkid=107&langid=1&mid=1. Assessed on January 18, 2021.

Census Data (2011) http://censusindia.gov.in/2011-Common/CensusData2011.html. Accessed 09 Oct 2019

Chandrasekar, N., V. Joevivek, and S. Saravanan. 2013. Coastal vulnerability and shoreline changes for southern tip of India— Remote sensing and GIS approach. Journal of Earth Science and Climate Change 4: 144.

Chen, W.B., Liu, W.C. and Hsu, M.H. (2012) Predicting typhoon-induced storm surge tide with a two-dimensional hydrodynamic model and artificial neural network model. Nat Hazards Earth Syst Sci 12:3799–3809

DNA India 2019. India has lost shore land of Nagpur city size to coastal erosion. Available at: https://www.dnaindia.com/analysis/column-india-has-lost-shore-land-of-nagpur-city-size-to-coastal-erosion-2735801. Assessed 06 December 2021

Dolan, A.H. and Walker, I.J. (2006) Understanding vulnerability of coastal communities to climate change related risks. *Journal of Coastal research*, pp.1316-1323.

Dube, S.K., Jain, I., Rao, A.D. and Murty, T.S. (2009). Storm surge modeling for the Bay of Bengal and Arabian Sea. *Natural Hazards*, **51:** 3-27.

Dwarakish GS, Vinay SA, Natesan U, Asano T, Kakinuma T, Venkataramana K, Jagadeesha PB, Babita MK (2009) Coastal Vulnerability Assessment of the Future Sea-Level Rise in Udupi Coastal Zone of Karnataka State, West Coast of India. Ocean Coast Manag 52:467-478. https://doi.org/10.1016/j.ocecoaman.2009.07.007.

Hegde AV, and Reju VR 2007. Development of Coastal Vulnerability Index for Mangalore Coast, India. J Coast Res 23: 1106–1111.

INCOIS. 2012. Coastal vulnerability Atlas of India. Hyderabad: Indian National Centre for Ocean Information Services.

Krishnan, P., Ananthan, P.S., Purvaja, R., Jeevamani, J.J.J., Infantina, J.A., Rao, C.S., Anand, A., Mahendra, R.S., Sekar, I., Kareemulla, K., Biswas, A., Sastry, R.K., Ramesh, R., 2019. Framework for mapping the drivers of coastal vulnerability and spatial decision making for climate-change adaptation: a case study from Maharashtra, India. Ambio 48, 192–212.

Kulp SA, Strauss BH (2019) New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. Nat Commun 10:4844

Kumar TS, Mahendra RS, Nayak S, Radhakrishnan K, Sahu KC (2010) Coastal vulnerability assessment for Orissa state, east coast on India. J Coast Res 26(3):523–534

Leary N, Adejuwon J, Bailey W, Barros V, Batima P, Caffera RM, Cinvanno S, Conde C, Comarmond AD, Sberbinin AD, Downing T, Eakin H, Nyong A, Opondo M, Osman-Elassha B, Payet R, Pulbin F, Pulbin J, Ratnisri J, Sanjak E, Maltitz MW, Yin Y, Ziervogel G (2008) For whom the bell tolls: Vulnerability in a changing climate. In: Leary N, Conde C, Kulkarni J, Nyong A, Pulbin J (eds) Climate change and vulnerability. Earthscan, London, pp 3–30

Mahendra R.S., Prakash C. Mohanty, Srinivasa Kumar T., Shenoi S. S. C., and Shailesh Nayak. (2010) Coastal Multi-hazard Vulnerability Mapping: A Case Study along the coast of the Nellore District, Andhra Pradesh, East Coast of

India. *Italian Journal of Remote Sensing*: Vol. 42, Issue 3, pp. 67-76. https://doi.org/10.5721/ItJRS20104235.

Mahendra, R. S., Mohanty, P. C., Bisoyi, H., Srinivasa Kumar T. and Nayak, S. (2011) Assessment and Management of Coastal Multi-hazard Vulnerability along the Cuddalore-Villupuram, East Coast of India using Geospatial Techniques. *Ocean and Coastal Management:* 54(4), 302-311, https://doi.org/10.1016/j.ocecoaman.2010.12.008

Mahendra, R.S., Mohanty, P.C., Francis, P.A., Sudheer Joseph, Balakrishnan Nair T. M. and Srinivasa Kumar T. (2021). Holistic approach to assess the coastal vulnerability to oceanogenic multi-hazards along the coast of Andhra Pradesh, India. *Environ Earth Sci,* 80, 651. https://doi.org/10.1007/s12665-021-09920-z

Maiti, S., S.K. Jha, S. Garai, A. Nag, R. Chakravarty, K.S. Kadian, B.S. Chandel, K.K. Datta, et al. 2015. Assessment of social vulnerability to climate change in the eastern coast of India. Climatic Change 131: 287–306

Mani Murali R, Ankita M, Amrita S, Vethamony P (2013) Coastal vulnerability assessment of Puducherry coast, India, using the analytical hierarchical process. Nat Hazards Earth Syst Sci 13(12):3291–3311

McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White. 2001. Climate change 2001: Impacts, adaptation, and vulnerability. Cambridge: Cambridge University Press.

Meiyappan, P., P.S. Roy, A. Soliman, T. Li, P. Mondal, S. Wang, and A. K. Jain. 2018. India Village-Level Geospatial Socio-Economic Data Set: 1991, 2001. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4CN71ZJ. Accessed 041 December 2020

Ojwang, G.O., J. Agatsiva, and C. Situma. 2010. Analysis of climate change and variability risks in the smallholder sector: Case studies of the Laikipia and Narok Districts representing major agro-ecological zones in Kenya. Rome: Food and Agriculture Organization of the United Nations.

Piya L, Maharjan KL, Joshi NP (2012) Vulnerability of rural households to climate change and extremes: Analysis of Chepang households in the mid-hills of Nepal. Selected paper prepared for presentation at the International Association of Agricultural Economics (IAAE) Triennial Conference, Foz do Iguacu, Brazil

Rao A. D., Upadhaya P., Hyder Ali H., Pandey S. and Warrier V. (2020). Coastal inundation due to tropical cyclones along the east coast of India: an influence of climate change impact. Natural Hazards (2020) 101:39–57 https://doi.org/10.1007/s11069-020-03861-9.

Saxena S, Purvaja R, Mary D, Ramesh R (2013) Coastal hazard mapping in the Cuddalore region, South India. Nat Hazards. 66:1519–1536. https://doi.org/10.1007/s11069-012-0362-7.

Sindhu T. and Rai, S.C. (2020) Monitoring shoreline changes along Andhra coast of India using remote sensing and geographic information system. Indian Journal of Geo Marine Sciences Vol. 49 (02), 218-224.

Somayajulu UV (2005). Cyclone in Andhra Pradesh: Damages and Response. National seminar on Population Environment and Nexus, Population Environment Centre, IIPS, Deonar, Mumbai, India.

Umamaheswari, T., Sugumar, G., Krishnan, P., Ananthan, P.S., Anand, A., Jeevamani, J.J.J., Mahendra, R.S., Infantina, J.A., Rao, C.S., (2021) Vulnerability assessment of coastal fishing communities for building resilience and adaptation: Evidences from Tamil Nadu, India. Environmental Science & Policy, Volume 123, Pages 114-130, ISSN 1462-9011, https://doi.org/10.1016/j.envsci.2021.05.009.

Velepucha, E.P.A., J.A.M. Chamba, N.A.A. Mendoza, T.L. Ojeda-Luna, N.S. Samaniego-Rojas, M.J. Furniss, C. Howe, and Z.H.A. Mendoza. 2016. Tropical ecosystems vulnerability to climate change in southern Ecuador. In Tropical Conservation Science, 1–17.

Wong, P.P., I.J. Losada, J.-P. Gattuso, J. Hinkel, A. Khattabi, K.L. McInnes, Y. Saito, and A. Sallenger, 2014: Coastal systems and low-lying areas. In:Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 361-409.

Tseng, W., D¨ornyei, Z., Schmitt, N., 2006. A new approach to assessing strategic learning: the case of self-regulation in vocabulary acquisition. Appl. Linguist. 27, 78–102.

Cronbach, L.J. 1951. Coefficient alpha and the internal structure of tests. Psychometrika 16: 297–334.

****

R S Mahendra Research Scholor **Sign:** **Date:**	**P A Francis** Scientist F, INCOIS **Research Guide** **Sign:** **Date:**